Renewable and Sustainable Energy Reviews 19 (2013) 678–691

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

The Brazilian energy matrix: From a materials science and engineering perspective

D. Pottmaier [a,*], C.R. Melo [b], M.N. Sartor [c], S. Kuester [a], T.M. Amadio [a], C.A.H. Fernandes [d], D. Marinha [a], O.E. Alarcon [a]

[a] Department of Mechanical Engineering, Federal University of Santa Catarina (UFSC), Campus Trindade, C.P. 476, Florianopolis, SC, Brazil
[b] Beneficent Association of the Coal Industry of Santa Catarina (SATC), Rua Pascoal Meller 73, C.P. 362, Criciuma, SC, Brazil
[c] Chemistry and Polymers Area, University Center Barriga Verde (UNIBAVE), Rua Pe. João Leonir Dall'Alba, s/n Murialdo, Orleans, SC, Brazil
[d] Civil Construction Department, Federal Institute of Santa Catarina (IFSC), Av. Mauro Ramos, 950 Centro, Florianopolis, SC, Brazil

ARTICLE INFO

Article history:
Received 2 August 2012
Received in revised form
19 November 2012
Accepted 20 November 2012
Available online 23 December 2012

Keywords:
Brazil
Energy matrix
Governmental program
National plan
Hydropower
Pre-salt
Materials science and engineering

ABSTRACT

An overview of the availability and affordability of energy sources and generation potential in Brazil is given in the present manuscript. Most of the information given here up-to-now was only accessible to Portuguese speakers, such as found in governmental plans for the energy sector. Brazilian public strategy for the following years concentrates on the promotion of more efficient energy utilization in different sectors of the society and also on diversifying its energy matrix. A perspective of programs, projects and technologies available in the country is also given. It is known that the Brazilian energy matrix is largely dominated by hydroelectric power, which relies on a consolidated infrastructure. However, recently discovered pre-salt layer of oil and natural gas presents new technological and scientific challenges for the professionals in the sector. National development and solidification of technologies for harnessing energy from the abundantly available biomass is yet another challenging task for Brazil. This manuscript not only presents the current Brazilian energy scenario and perspectives but also intends to identify some opportunities for investment and research, especially in the areas of materials science and engineering. A vision for what is expected for the Brazilian energy matrix based on current governmental actions and future technology is given in this perspective, while maintaining a critical overview on how to achieve optimum results with a balanced economic and environmental approach.

Contents

* Corresponding author.
E-mail address: daphiny@gmail.com (D. Pottmaier).

1364-0321/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2012.11.063

1. Introduction

Energy consumption is an important indicator in revealing development stages and living standards of societies. It is often found that the major consumption share in developed countries is done by the industrial sector. According to Enerdata World 2011 yearbook, Brazil was the 7th largest energy consumer with 263 Mtoe (3,058,690 GWh) and the 9th primary producer with 247 Mtoe (2,872,610 GWh) [1]. In the last year only, total primary energy production in Brazil has increased 6.6% (4.0% world average value) and energy consumption showed an even greater increase of 10.0% (5.5% world average value). A similar trend was observed in other two countries of the so-called BRIC group, the more pronounced being China [2] According to the Brazilian Institute of Geography and Statistics (IBGE) in the last 10 years there was a population grown of 10.9% (from 169,799,170 inhabitants in 2000 to 190,732,694 in 2010) followed by an energy consumption growth of 40.7% (181 MToe in 2000 to 255 MToe in 2010) [3]. Having that in mind, Brazilian government over the past decade made great strides in increasing its total energy production as part of a Growth Acceleration Plan (PAC) [4] together with an specific National Energy Plan (PNE) [5]. The PAC2 for the Energy Sector has concentrated on investments in: generation and transmission of electricity, exploration of oil and gas, renewable fuels, and mineral research [4]. Estimation of the Brazilian Energy Ministry is that the country will need to invest about 550 billion dollars into the energy industry to meet market demand by 2019 [6]. The PNE has designed technological and efficiency measures in different sectors such as equipment update, cogeneration, re-use of left-over biomass, insertion of natural gas, penetration of ethanol, more efficient use of diesel, and gradual reduction of road transport [5].

Brazil is incorporating two strategies regarding the energy sector: one by keeping the matrix clean and renewable, focusing on its hydraulic potential; and another by the promotion of conservation and efficient use, through various governmental programs [7]:

– PROCEL (National Program on Conservation of Electrical Energy) created in 1985 to be responsible for actions on the industry, buildings, cities, public illumination and other sectors [8];
– CONPET (National Program on Rationalization of the Use of Oil- and Natural Gas-based products) established in 1991 to promote the efficient use of oil and natural gas in transportation, residential, commerce, industry and agriculture [9];
– PBE (Brazilian Program on Labeling) signed in 1984 to give useful information related to energy efficiency of a variety of products directly to consumers [10];
– PNMC (National Plan on Climate Changes) created in 2007 to promote the mitigation of greenhouse emissions in a cooperative world effort [11].

In this context, there is a collaborative action between the Ministry of Mines and Energy (MME), state companies Eletrobras and Petrobras, and regulating agencies National Agency of Electrical Energy (ANEEL) [12], National Agency of Oil, Natural Gas and Biofuels (ANP) [13] and National Institute of Metrology, Normalization and Industrial Quality (INMETRO) [14]. Eletrobras and Petrobras are responsible for the execution, while ANEEL, ANP and INMETRO are responsible for monitoring these programs, among others, all by the National Council on Energy Policy (CNPE) [15] through a National Program on Energy Efficiency (PNEE) [16]. Lastly, there is another sate company called Entrepreneurship of Energy Research (EPE) that provides support in the research and planning of the energy sector [17].

Apart from the country division in 27 administrative units (26 states and 1 federal district) or its 5 regions, it can be visualized as 3 main geo-economical complexes (see Fig. 1):

– South-Center: Sao Paulo (SP), Rio de Janeiro (RJ), Minas Gerais (MG), Espirito Santo (ES), Parana (PR), Santa Catarina (SC), Rio Grande do Sul (RS), South of Mato Grosso (MS), Goias (GO), South of Tocantis (TO), Mato Grosso (MT), Federal District (DF);
– Northeast: North of Minas Gerais (MG), Bahia (BA), Sergipe (SE), Alagoas (AL), Pernambuco (PE), Paraiba (PB), Rio Grande do Norte (RN), Ceara (CE), Piaui (PI), East of Maranhao (MA);
– Amazon: Amazonas (AM), Acre (AC), Amapa (AP), Para (PA), Rondonia (RO), Roraima (RA), West of Maranhao (MA), Mato Grosso (MT).

Power generation sources depend on geo and economic characteristics of the region. In Brazil the highest population density is found along the coast and in the south-center part. It is therefore only natural that a concentration of the main power plants is observed in these regions. In numbers, live-updated information, given in the ANEEL webpage [18], reports a generation capacity of 117,527,167 kW from 2,612 units in operation. In addition, another 26,725,722 kW are planned to issue from 170 units already under construction and 21,480,443 kW from 554 units already planned for the following years (Table 1).

The Brazilian energy matrix (Fig. 2) is composed mostly by hydropower (65.58%), gas (10.59%), biomass (7.35%) and oil (5.67%) mainly for fueling the transport sector, nuclear (1.59%) counts for together coal (1.54%) and eolian (1.22%) contributions, and finally,

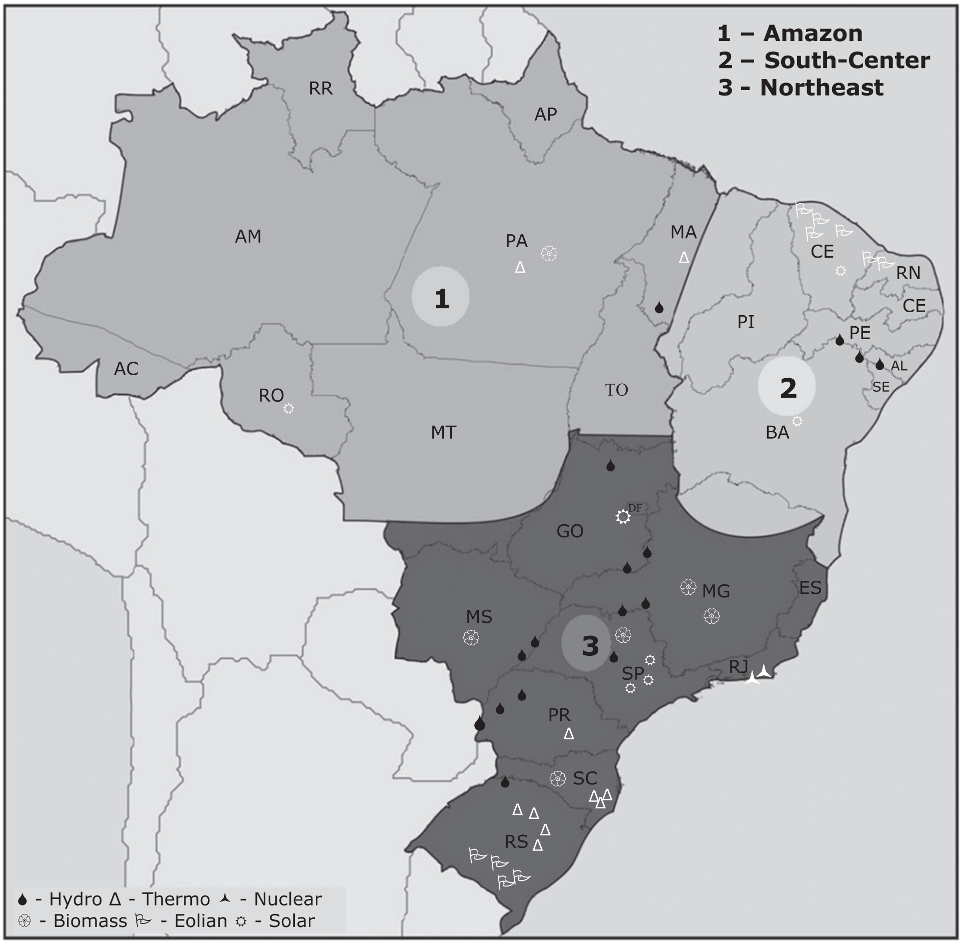

Fig. 1. Map of Brazil with top power plants by energy source.

Table 1
Generation power units in operation, under construction, issued in Brazil [18].

Power unit type	Units	(kW)	%
Hydroelectric Energy Unit (UHE)	182	78,530,049	66.59
Thermal Electric Unit (UTE)	1550	31,656,798	26.84
Small Hydroelectric Central (PCH)	429	3,991,785	3.38
Thermal Nuclear Unit (UTN)	2	2,007,000	1.7
Eolian Generation Unit (EOL)	75	1,519,042	1.29
Hydroelectric Generation Central (CGH)	380	224,886	0.19
Photovoltaic Unit (UFV)	8	1494	0
In operation—Total: 2626 units		Power: 117,931,054 kW (100%)	
Hydroelectric Energy Unit (UHE)	11	18,252,400	67.08
Thermal Electric Unit (UTE)	44	4,970,197	20.27
Eolian Generation Unit (EOL)	57	1,467,090	5.39
Thermal Nuclear Unit (UTN)	1	1,350,000	4.96
Small Hydroelectric Central (PCH)	56	623,277	2.29
Hydroelectric Generation Central (CGH)	1	848	0
Under construction—Total: 170 units		Power: 27,208,304 kW (100%)	
Thermal Electric Unit (UTE)	150	11,768,573	54.79
Eolian Generation Unit (EOL)	197	5,698,190	27.23
Hydroelectric Energy Unit (UHE)	11	2,179,042	10.41
Small Hydroelectric Central (PCH)	134	1,815,400	8.68
Hydroelectric Generation Central (CGH)	61	40,698	0.19
Wave Generation Central (CGU)	1	50	0
ISSUED—Total: 551 units		Power: 20,922,731 kW (100%)	

imported energy (6.46%). Imported energy comes from neighboring countries such as Paraguay (5,650,00), Argentina (2,250,000), Venezuela (200,000), and Uruguay (70,000) totalizing 8170 kW [19].

Brazil contains over 30% of the world's tropical rainforests and 45.2% of energy consumed is renewable. It is undoubtedly a major player in discussions concerning global environmental issues.

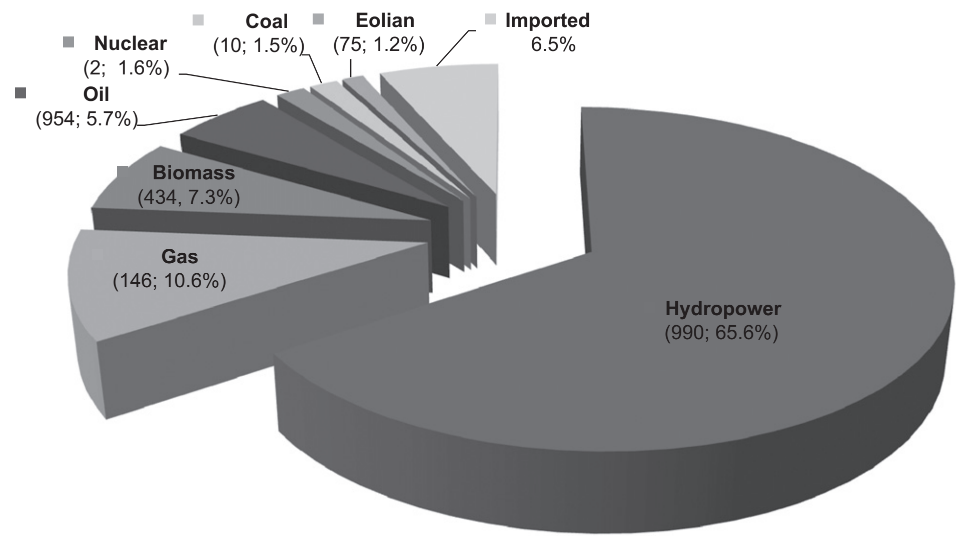

Fig. 2. Energy matrix of Brazil in 2012 by fuel source (units, %) [19].

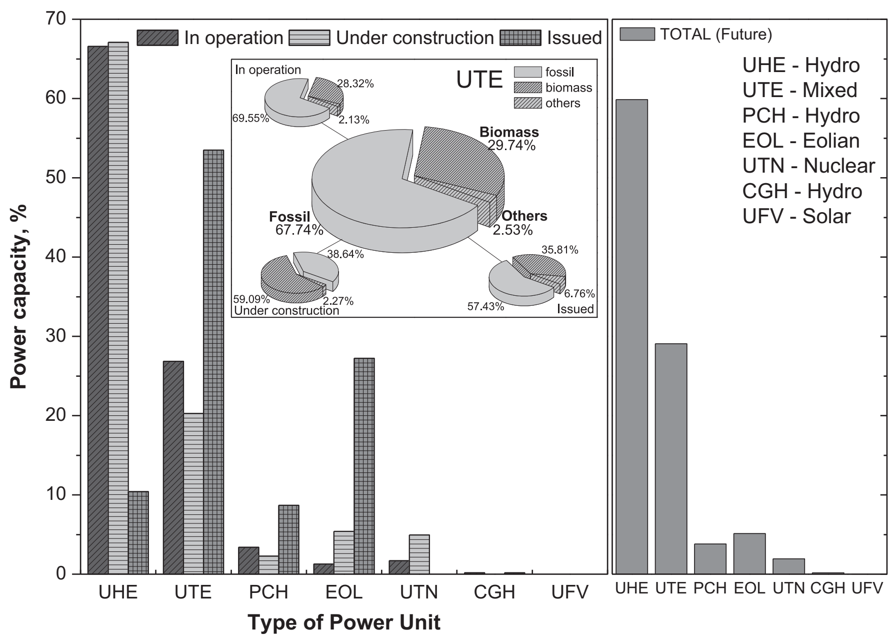

Fig. 3. Generation power units in operation, under construction, issued in Brazil [18].

However, a significant change to the present energy matrix is expected with the discovery of pre-salt layer by Petrobras [20,21], a future Nuclear Power Plant (under construction), and additional 150 Thermal Power Plants already planned (Fig. 3). These actions will increase the use of fossil fuels, which is today one of the cleanest in the world. Thus, it is expected that this local strategy will have a global environmental impact [22]. Still, the country is going through a transitory period in which rapid industrial development and demographic expansion cause a great demand from current technological infrastructure. The industrial sector presented clear shifts in main energy sources over the past year due to cost and supply variations [23], and hopefully, low-carbon alternatives may sought after in the coming decades [24].

1.1. Hydropower (82,735 MW)

Brazilian energy matrix is mainly sustained by hydropower (more than 80 GW generated) placing the country at the top of sustainability on energy generation and consumption. Hydropower is harnessed mainly by big dams called UHE. As already shown, electricity generated from hydropower sources is classified according to its installation type as: Hydroelectric Energy Units (UHE) [25], Hydroelectric Generation Centrals (CGH) [26], and Small Hydroelectric Centrals (PCH) [27]. The country still counts with the largest hydroelectric power plant in the world as regards to the actual energy generation, the Itaipu Binacional. Itaipu with 14,000 MW of installed power and its 20 generators supplies about 17.0% of the electricity consumed in Brazil today [28]. After a controversial decision, construction of Belo Monte in the Amazonia region has started with installed capacity of 11,233 MW, which ranks third in the world. According to PAC2 [4], other 76 projects were issued summing up other 26,252 MW to Brazil electricity grid. Recently, it was also issued the construction of a Wave Generation Unit (CGU—Central Geradora Undi-Elétrica) in the northeast region (Porto do Pecem, Ceara) with a power capacity of 50 kW [29].

1.2. Oil and gas (13,370 MW)

International Energy Agency (IEA) states that the total world oil demand reached 89.3 million barrels per day (mbd) up until September this year, representing an increase of 1.0 mbd (1.2%) in comparison to 2010, and also estimated a further growth of 1.4 mbd (+1.6%) which gives us a 90.7 mbd in 2012 [30]. Brazilian pre-salt deposits (an example of unconventional offshore production of gas and oil) cover an area of 800 km long and 200 km wide, being located in five states including Santa Catarina, Parana, Sao Paulo, Rio de Janeiro and Espirito Santo. The depth varies from 1,000 to 2,000 m of water and between 4,000 and 6,000 m of depth underground, so amounting up to 8,000 m from the sea surface, including a layer that varies from 200 to 2,000 m of salt [21].

1.3. Biomass (9,130 MW)

Biomass is already a major source in the Brazilian energy matrix, and is mainly extracted from the sugar–ethanol sector. It is, nevertheless, beneath its potential. Nowadays, cogeneration from biomass totals 8 GW, of which 6.3 GW are from sugarcane bagasse. Existing boilers have been working since the 1970s and are obsolete. Estimations predict that the sugarcane sector alone could generate 39.5 GW by replacing existing boilers with new, more efficient ones. In Brazil, there are 325 plants in operation crushing 425 million tons of sugarcane per year of which half of that are used for ethanol production. Moreover, PNE scenario predicts a fourfold increase of biodiesel production as part of the National Biodiesel Production and Use Program by the law 11.097 of 2005, with a compulsory mix of up to 20% of biodiesel (designated as B20, the 5% as B5) into the fossil diesel for use in Brazil. Lately, ANEEL reports 13 biogas thermoelectric plants in operation with a total potential above 69 MW [18].

1.4. Nuclear (2,000 MW)

At present Brazil has two operating thermonuclear power plants with a total capacity of 2,007,000 kW [41], contributing with a share of 1.60% to the Brazilian matrix. Construction of a third thermonuclear power plant is on the way with a capacity for 1,350,000 kW power generation and to be fully running by 2015 [42]. In addition, Brazilian uranium reserves have been proven to be vast, with an estimated 800,000 t of U_2O_3 [43]. Even with a total potential of 36 GW and an enrichment facility under construction [44], increase of nuclear power participation into the energy matrix is not likely to occur.

1.5. Coal (1,945 MW)

Coal consumption at a global level increased 5.3% in 2010 driven by Chinese demand (45.0%) and helped by Brazilian consumption with a 21.0% increase, returning to its pre-crisis levels [1]. The IEA and BP/British Petroleum company recently reported that total coal reserves are about 1 trillion tons, enough to supply the energy demand at current levels for at least 190 years [31,32]. In Brazil, the largest coal reserves are located in the states of Santa Catarina and Rio Grande do Sul [33]. Despite the nature of coal fossil fuel and its potential for pollution, it will also play an important role in the Brazilian energy matrix for some years to come [5]. Studies to enhance efficiency in coal gasification as well as Carbon capture and sequestration (CCS) have significantly advanced [34–36] but in order to effectively mitigate the negative impacts of the use of fossil fuels, upcoming strategies will depend on materials research [37]. In Brazil since the 1980s, Petrobras has been doing CCS especially focusing on oil enhancement recovery.

1.6. Eolian (1,520 MW)

There are 73 wind power plants currently installed in Brazil, 26 other plants under construction and 103 plants to be built [18]. Governmental program on infrastructure PROINFRA, established by the law 10.438 in 2002, states that Brazil will rely on wind generation as its main renewable alternative and it will be subsidizing the implementation of this technology into the public electrical grid. Calculations presented at the Atlas for Brazilian Potential of Wind Power Generation estimates harvest onshore to reach between 143.5 GW or 272.2 TWh per year, with 75 GW only in the northeast region [38].

1.7. Solar (1.5 MW)

Brazil has large areas with high solar irradiation, but the lack of public policy together with high prices resulted in a very low exploration of this source [39]. It was only in 2011 that the first installation for the generation of electricity by photovoltaic panels was connected to the grid. Although there are some states with experimental systems connected to the grid [40], the largest use is in stand-alone systems. Apart from residential utilization, these systems are being explored in rural and isolated areas, especially in the Amazonian region, where large distances make the construction of transmission grids unsuitable.

1.8. Hydrogen

Brazil has a clean but poorly diversified energy matrix. Hydrogen-based technology could support and complement other intermittent renewable sources. Research and technologies for a hydrogen-based power which is still in early development are suffering from the lack of funding. Efforts are mainly concentrated in three areas: proton exchange membrane fuel cells, solid oxide fuel cells, and catalysts for ethanol reforming [45]. Such initiatives started in 2002 with PROCaC (now $ProH_2$) by MCT (Ministry of Science and Technology) and some companies (e.g. Petrobras) resulting in a gain of expertise by some groups in the country [46–53].

1.9. Materials perspective

Finally, the country is known by its rich commodities range; however, in most cases they are exported and imported back as processed materials and components, including in the energy sector. Recently, the Brazilian government has realized the importance of materials in enhancing efficiency and lowering technological costs. Further evidence came last year when the US government officially recognized the importance of materials in launching the Materials Genome Initiative for Global Competitiveness [54]. A new materials-based economy is expected in the near future, and with it the production-processing-disposal of materials wastes will be focusing not only on materials themselves, but also in their role in energy-harnessing technology. The old energy economy fueled by oil, coal, and natural gas is being systematically replaced by one powered by wind, solar and biomass sources of energy. Materials science has been the enabler for turning these technologies into reality, as there would be no solar power without photovoltaic materials, less efficient wind power without high reinforced composites, and no electrical cars without lithium batteries, to name a few. Still Brazil only invests 1.01% of its GDP (0.54% private sector and 0.57% public) on research. According to Science and Technology minister this is due to a “passivity” of the companies, as they prefer paying for

the already available technology. Such mindset is observed in the energy sector and it will be also part of the discussion in the present review article, which is divided in sections for renewable sources (hydropower, biomass, eolian and solar energy), for fossil-fuels sources (coal, oil and natural gas), then nuclear power and hydrogen energy.

2. Renewable sources of energy

Even though fossil fuels dependency on is well established, investments in renewable energy, led by wind and solar, are a current trend. In Brazil, hydropower from big dams is used mainly to generate electricity for industry and residences; there are plans to fill the gap of the country's projections of energy consumption in the near future.

2.1. Hydropower: rivers, tides, and waves

Unlike fossil fuels, hydro resources are widely spread around the world and it is the most exploited energy source in Brazil. Hydropower or hydroelectricity is a well-established, cost-effective renewable energy, and it has been mainly harnessed from rivers by the building of dams. Nowadays, however, it is also possible to harness the energy of tides and waves using smaller in-stream turbines. As aforementioned, Brazil gets the bulk of its electricity [19] from river dams placing the country at the top in the renewable energy rank [1,22,31]. Hydropower technologies are classified mainly according to their turbines by ANEEL [12] into the following categories: Hydroelectric Energy Units (UHE) with 182 units generating 78,456,459 kW/66.76% [25], Hydroelectric Generation Centrals (CGH) with 376 units generating 227,854 kW/0.19% [26], and Small Hydroelectric Centrals (PCH) with 427 units generating 3,939,205 kW/3.35% [27]. Table 2 shows the top UHE by power potential, altogether generating more than half of the electricity in the country, and Table 3 shows the top PCH (under 30 MW in the Brazilian context).

The hydro-turbines convert water pressure into mechanical shaft power that can be used to drive and electric generator. Reaction turbines used in low (< 30 m) or medium (30–300 m) head application and impulse turbines in very high (> 300 m) head applications. Mechanical power P, (in Watts) produced at the turbine shaft can be estimated by

$$P = \eta_t \rho_w g Q h$$

where η is the hydraulic efficiency of the turbine, ρ is the density of water (Kg/m^3), g is the acceleration of gravity (m/s^2), Q is the discharge (m^3/s) and h is the water head acting on the turbine (m). Specifically, η is mainly a function of pitting (extremely localized corrosion) and is majorly affected by surface hardness [55]. Careful choice of adequate materials is therefore required. Materials' wear and tear includes pitting from cavitation, fatigue cracking, and abrasion from suspended solids in the water. Still, present turbines can run for decades with very little maintenance [56]. Steel elements are repaired after cut or ground out of the damaged areas, and then welded back up to original or improved

Table 2
Top UHE—by power generation in Brazil, 2012 [25].

Name	(kW)	Holder	City, State	River
Itaipu	7,000,000	100% Itaipu Binacional	Foz do Iguaçu, PR	Parana
Tucurui I and II	8,370,000	100% Centrais do Norte S/A	Tucurui, PA	Tocantins
Ilha Solteira	3,444,000	100% Cia Energetica de Sao Paulo	Ilha Solteira, SP Selviria, MG	Parana
Xingo	3,162,000	100% Cia Hidroeletrica do Sao Francisco	Caninde Sao Francisco, SE Piranhas, AL	Sao Francisco
Paulo Afonso IV	2,462,400	100% Cia Hidroeletrica do Sao Francisco	Delmiro Gouveia, AL Paulo Afonso, BA	Sao Francisco
Itumbiara	2,082,000	100% Furnas Centrais Eletricas S/A	Arapora, MG Itumbiara,GO	Paranaiba
São Simao	1,710,000	100% CEMIG Geraçao e Transmissao	Santa Vitoria, MG Sao Simao, GO	Paranaiba
Foz do Areia	1,676,000	100% Copel Geraçao e Transmissao S/A	Guarapuava, PR Mangueirinha, PR Pinhao, PR	Iguaçu
Jupia	1,551,200	100% Cia Energetica de Sao Paulo	Castilho,SP Tres Lagoas,MS	Parana
Porto Primavera	1.540.000	100% Cia Energetica de Sao Paulo	Anaurilandia, MS Teodoro Sampaio, SP	Parana
Luiz Gonzaga	1,479,600	100% Cia Hidroeletrica do Sao Francisco	Gloria, BA Jatoba, PE	Sao Francisco
Ita	1,450,000	60.5% Ita S/A 39.5% Tractebel S/A	Aratiba, RS Ita, SC	Uruguai
Marimbondo	1,440,000	100% Furnas Centrais Eletricas S/A	Fronteira, MG Icem, SP	Grande
Salto Santiago[a]	1,420,000	100% Tractebel Energia S/A	Saudade do Iguaçu, PR	Parana
Agua Vermelha[a]	1,396,200	100% para AES Tiete S/A	Indiapora, SP Iturama, MG Ouroeste, SP	Grande
Serra da Mesa	1,275,000	100% Furnas Centrais Eletricas S/A	Cavalcante, GO Minaçu, GO	Tocantins
Segredo	1,260,000	100% Copel Geraçao e Transmissao S.A	Guarapuava, PR Mangueirinha, PR Pinhao, PR	Iguaçu
Salto Caxias	1,240,000	100% Copel Geraçao e Transmissao S.A	Leonidas Marques, PR Realeza, PR Salto do Lontra, PR	Iguaçu
Furnas	1,216,000	100% Furnas Centrais Eletricas S/A	Joao Batista do Gloria, SP Sao Jose da Barra, MG	Grande
Emborcaçao	1,192,000	100% CEMIG S/A	Cascalho Rico, MG Catalao, GO	Paranaiba
Machadinho	1,140,000	25.74% Alcoa Aluminio S/A 27.52% Cia Brasileira de Aluminio 5.53% Cia Estadual de Geraçao e Transmissao de Energia Eletrica 2.73% Departamento Municipal de Eletricidade de Poços de Caldas 5.27% InterCement Brasil S.A 19.28% Tractebel Energia S/A 8.29% Valesul Aluminio S/A 5.62% Votorantim Cimentos S.A.	Maximiliano de Almeida, RS Piratuba, SC	Pelotas
Salto Osorio[a]	1,078,000	100% Tractebel Energia S/A	Quedas do Iguaçu, PR	Iguaçu
Estreito	1,050,000	100% Furnas Centrais Eletricas S/A	Pedregulho, SP Sacramento, MG	Grande
Sobradinho	1,050,000	100% Cia Hidroeletrica do Sao Francisco	Sobradinho, BA	Sao Francisco
Total: 182 units			**Power: 78,456,459 kW (66.76 %)**	

[a] PIE: Independent energy production, Rest of them SP: Public service (on the grid).

Table 3
Top PCH—by power generation in Brazil, 2012 [25]. PIE: Independent energy production, APE: Auto-production of energy.

Name	Issued (kW)	Check (kW)	Grid	Holder	City, State	River
Nova Mauricio	29,232	29,232	APE	100% Vale S/A	Leopoldina—MG	Novo
Julio de Mesquita Filho (Foz do Chopim)	29,072	29,072	PIE	100% Foz do Chopim Energetica Ltda.	Cruzeiro do Iguaçu—PR	Chopim
Eng^{o} José Gelasio da Rocha	24,435	24,435	PIE	100% Hidropower Energia S/A	Pedra Preta—MT	Ribeirao Ponte de Pedra
Palanquinho	24,165	24,165	PIE	100% Serrana Energetica S/A	Caxias do Sul—RS Sao Francisco de Paula—RS	Lajeado Grande
Criuva	23,949	23,949	PIE	100% Criuva Energetica S/A	Caxias do Sul—RS Sao Francisco de Paula—RS	Lajeado Grande
Salto Maua	23,859	23,859	APE	100% Klabin S/A	Telemaco Borba—PR	Tibagi
Calheiros	19,528	19	PIE	100% Calheiros Energia S/A	Jesus do Itabapoana—RJ	Itabapoana
Santana I	14,758	14,758	PIE	100% Firenze Energetica S.A.	Nortelandia—MT	Santana
Pontal do Prata	13,774	13,774	PIE	100% Rialma Cia Energetica V S/A	Apore—GO	Prata
Mello	10,685	9.54	APE	100% Vale S/A	Rio Preto—MG	Santana
Total: 427 units					**Power: 3,939,205 kW (3.35%)**	

profiles. Even with elaborate welding procedures with the highest quality repairs [57], old turbine runners may have a significant amount of excess stainless steel by the end of their lifetime diminishing its power efficiency.

The first universally recognized procedure in order to avoid hydro-abrasive erosion is by removing particles greater than 1 mm using large headwater reservoir with enough volume to settle them down. Regardless, substantial quantities of aggressive particles inevitably pass by these settling chambers, thus turbines have to be designed for, and its surfaces protected against, the maximum expected particle load downstream. Protective coatings fall into two categories: hard coatings such as welded Stellite, and thermally applied tungsten carbide; and soft coatings, which are typically a brush, trowel, or spray-on polymer [58].

Small hydropower is one of the most valuable sources of remote off-grid rural electrification, due to its potential to improve the quality of rural and indigenous life. Multiple purpose projects for drinking water and irrigation systems can take the advantage of install small hydro schemes [59].

Use of water in hydroelectric systems is a throughput with minimal water loss when compared to thermal electric fossil fuel powered which use steam instead. An example of optimal dam is the run-of-the river unit, with no reservoir. To elucidate, power potential in operation/under construction (i) and estimated or in study (ii) of Brazilian rivers by region are [60]:

– Amazon: 16,023 MW (i)+59,218 MW (ii);
– South-Center: 61,255 MW (i)+59,777 MW (ii);
– Northeast: 23,140 MW (i)+13,384 MW (ii).

Giant projects for tidal power generation are under consideration in several other countries: Canada, China, New Zealand, India, Russia, Turkey and the United Kingdom [61]. In the United States and Australia [62], focus is on smaller tidal facilities with different types of generators on streams.

Regardless, wave power though is somewhat underdeveloped when compared to tidal, and it is only now attracting attention of both engineers and investors. The world's first wave farm, a 2 MW facility, but intended to be expanded to 22 MW, is already operating off the coast of Portugal [63]. Projects of constructing a 1,000 MW tidal and wave power off the coast of Ireland and the United Kingdom are underway [22]. In Brazil, the construction of a Wave Generation Unit (CGU) in the northeast region (Porto do Pecem, in Ceara) with a 50 kW power potential has already been issued [29]. Buildings construction may start this year under the responsibility of the infrastructure secretary of the Ceara state. Thus, not different from other parts in the world such initiatives to promote renewable energy generation are funded by governmental initiatives as power prices may not be able to compete with other power sources.

While some sort of hydropower is in operation in over 150 countries, equipment manufacturing is limited to a few countries around the world. Even fewer companies have a global manufacturing capability (Dongfang Electric—China, Voith—Germany, Andritz—Austria, Alstom—France, IMPSA—Argentina, Toshiba—Japan) and others a more localized approach. With reported increase in sales, large manufactures have been investing in new plants and acquiring smaller firms to keep up with changing technologies. This year, IMPSA is expected to open a new production facility in Brazil. The two main companies operating in the country are: Alstom—ABB (former Mecanica Pesada) in Sao Paulo producer of Bulb and new generation turbines, N.H. Geradores in Minas Gerais specialized in Pelton turbines, Voith S.P. in Sao Paulo together with former Mecanica Pesada have produced the 18 Francis turbines for Itaipu Binacional.

2.2. Biomass energy: solid, liquid and gaseous

Photosynthesis has proven itself as a large-scale carbon cycle in which about 100 Kg of carbon per year moves back and forth between the atmosphere and biological matter. Biomass is basically a stored mixed source of chemical and solar energy collected by plants during the photosynthesis process whereby carbon dioxide is captured and converted to plant materials mainly in the form of cellulose, hemi-cellulose and lignin. The term "biomass" therefore covers a range of organic materials recently produced from plants, and animals [64]. Biomass can be re-converted into useful energy by different routes through physical (drying, crushing), thermochemical (combustion, gasification, pyrolysis, liquefaction) and biological processes (fermentation, digestion).

Biomass is an interesting option for electricity production in parts of the world where supplies of residues from agriculture or the forest products industry are abundant [65], as in Brazil, for example. But the rapid development of a second-generation of liquid biofuels may create competition for feedstock between the two uses [22].

Main biomass routes spread in the country are the direct combustion of sugarcane with 348 power plants summing up 80% of all energy produced from biomass (Table 4). Other sources of biomass include wood, black-liquor, rice, bagasse straw, but sugarcane is the main source representing almost 80% of the total in 2011 [66].

In the long term, efforts are needed to bring about a significant increase in the efficiency of the entire combustion–generation system. Currently, typical efficiencies are in 20–25% for electricity generation from biomass sources. It would be more effective to

Table 4
Biomass power plants by source and Top UTE by power generation in Brazil, 2012 [18].

Fuel source	Quantity	Power (KW)	Total%	Relative %
Sugar-cane	348	7,267,988	5.8	80.8
Black-liquor	14	1,245,198	0.99	13.8
Wood	43	376,535	0.30	4.2
Biogas	18	76,308	0.06	0.8
Rice	8	32,608	0.03	0.4
Total: 431 units			**Power: 8,998,637 kW (7.18%)**	
Fuel	**Power (kW)**	**Holder**	**City, State**	**Source**
Bioenergia Costa Rica	79,828	100% Cia Brasileira de Energia Renovável	Costa Rica, MS	Sugarcane
Klabin Correia Pinto	37,822	100% Klabin S/A	Correia Pinto, SC	Blackliquor
Delta	31,875	100% Usina Caete S/A	Delta, MG	Sugarcane
Eldorado	25,019	100% Usina Eldorado Ltda.	Rio Brilhante, MS	Sugarcane
Ibira	7,952.50	100% Pedra Agroindustrial S/A	Santa Rosa de Viterbo, SP	Sugarcane
Frutal	16,092	100% Frutal Açucar e Álcool S.A.	Frutal, MG	Sugarcane
Alcoa Porto	5,644	100% Petrobras Distribuidora S/A	Juruti, PA	Sugarcane
Total: 431 units			**Power: 8,998,637 kW (7.18 %)**	

Table 5
Top EOL—by power generation in Brazil, 2012 [70].

Name	Power (kW)	Holder	City, State	Grid[a]
Praia Formosa	104,400	100% Formosa S/A	Camocim, CE	IP
Elebras Cidreira	70,000	100% Elebras S/A	Tramandai, RS	IP
Canoa Quebrada	57,000	100% Bons Ventos S/A	Aracati, CE	IP
Icaraizinho	54,600	100% Icaraizinho S/A	Amontada, CE	IP
Alegria I	51,000	100% New Energy Options S/A	Guamare, RN	IP
Osorio	50,000	100% Ventos do Sul Energia S/A	Osorio, RS	IP
Sangradouro	50,000	100% Ventos do Sul Energia S/A	Osorio, RS	IP
Dos Indios	50,000	100% Ventos do Sul Energia S/A	Osorio, RS	IP
Bons Ventos	50,000	100% Bons Ventos S/A	Aracati, CE	IP
Rio do Fogo	49,300	100% Energias Renovaveis Brasil S/A	Rio do Fogo, RN	IP
Total: 73 units			**Power: 1,471,192.20 kW (1.17%)**	

[a] IP: Independent Production.

focus research efforts on generation from biomass gasification, and to phase out large-scale combustion facilities. Materials research could make substantial contributions to biomass technologies in two main areas:

– refractory materials for a better thermal insulation and hotter fuel gases;
– catalysts for fuel processing methods for a more complete combustion [67].

The intensive use of biomass is typically associated with underdevelopment, since it is an energy source readily available and utilized by means of inefficient technologies. In addition, cultural and economic factors, plus inadequate regulation, also contribute to inefficiencies in the biomass energy sector. Thus, it requires a significant cultural shift in all segments of the society, and also institutional guidelines highlighting the role of government as regulator in the energy sector and an initial provider of funding. Transformation and more efficient use of sugarcane and its derivatives may reduce even more the Brazilian carbon footprint. Review works related to biomass technologies and current status in the country are given in more detail elsewhere [60,68–70].

2.3. Eolian: onshore and offshore

Kinetic energy from the wind is converted into mechanical energy by turbines and finally into electricity. World potential of wind energy was recently technically recalculated as less than 40 TW [71] with effectively installed capacity in 2012 of 0.05 TW in the world [72] and of which 52 MW in Brazil [4]. First wind turbine installations – Cerro Chato with 30 MW, Fazenda Rosário with 8 MW, Fazenda Rosario III with 14 MW – are located in Rio Grande do Sul (RS), southernmost state in Brazil (Table 5). Two more installations are already under construction in RS, eight in Bahia (BH), and thirteen in Rio Grande do Norte (RN) with about 30 MW each. PAC2 also has as a preparation action or additional thirteen in RS, one in Sergipe, twenty-six in BH, twenty-six in Ceara, and fourty-nine in RN, all of them states on the Brazilian coast. Thus, wind installed potential will pass from 73 to 141 Eolian Energy Usines ("UEE/Usina de Energia Eolica" in Portuguese) [4]. In 2010, Brazil was placed at 21st position by the World Wind Energy Agency (WWEA) for its installed power capacity [73]. When finally connected to the main electrical grid, eolian energy will contribute significantly to the Brazilian energy matrix.

Even though much investment has been made in wind farm construction, there is a lack of research and technology in this area; and main components are being imported from the largest manufactures in other countries [74].

Main challenges regarding materials in this sector involve optimum combination of stiffness and low weight in order to prevent excessive deflection in the blades; increase of toughness with minimization of defects to prevent buckling failure; and enhancement of fatigue life under variable loading conditions. Moreover, as wind farms and turbines are being moved offshore corrosion behavior will also become a crucial criterion on materials selection. In summary, materials properties underpin a scenario

Table 6
UFV–Photovoltaic installations operating in Brazil, 2012 [40].

Name	Power (KW)	Holder	City, State
Taua	1,000	100% MPX Ltda.	Taua, CE
Pituaçu solar	404.80	100% Desportos do Estado	Salvador, BA
Embaixada Italiana	50.0	100% Embaixada Italiana	Brasilia, DF
Araras	20.48	100% FAPEU	Nova Marmore, RO
IEE	12.26	100% IEE	Sao Paulo, SP
UFV/IEE	3.0	100% IEE	Sao Paulo, SP
Aeroporto Campo de Marte	2.12	100% EBIA	Sao Paulo, SP
PV Beta test site	1.7	100% Dupont do Brasil S/A	Barueri, SP
Total: 8 units			**Power: 1,494.36 kW**

with predominance of blades made of reinforced composites, probably with the use of natural materials rather than oil-based ones [75].

2.4. Solar energy: photovoltaic panels and thermal collectors

Energy from the sun can be harnessed with photovoltaic panels (PV) and thermal collectors (TC). Whereas solar PV cells, which are often silicon-based semiconductors and thin films, convert sunlight directly into electricity, solar thermal collectors convert it into heat. Solar energy presents itself as a growing alternative. While representing a small percentage (less than 0.1%) of the global energy production, it is the source of renewable energy with the fastest growing in percentage around the globe. It is estimated that by 2030 the production of solar energy will reach 29% of total renewable energy sources (1,619 TWh), or 4.9% of a projected total of 33,000 TWh of energy produced in the world [76].

PVs in the world electrical grid are built by various technologies and may be placed into the main materials categories: monocrystalline silicon, polycrystalline silicon, amorphous silicon; and other semiconductor materials mostly of bulk crystals made of gallium asenite (GaAs), cadmium telluride (CdTe), and cooper–indium disselenite ($CuInSe_2$). Worldwide, Germany accounts for about 9.8 GW, followed by Spain (3.4 GW), and Japan (2.6 GW) [77]; all these countries profited from governs incentive in policies and subsidies for the installation of PVs on residential and industrial buildings as well as for the construction of power plants that could be connected to the main grid.

In Brazil, the lack of public policies to encourage the use of photovoltaic panels isolated or connected to the grid [39] associated to low competitive price compared to the cost of kilowatts produced by coal power plants is the determining factor. In 2011, the first power plant with a capacity to generate 1 MW using PVs was inaugurated in the northeast region (in Taua, Ceara). Although there are a few experimental systems connected to the grid in some states, the largest use is in stand-alone systems (Table 6). PV installations are growing in rural and isolated areas, especially in the northern region (Amazon state), where large distances make it impossible to build transmission grids and islands, signal buoys and telephone transmission towers. With the reduction of the PV prices, construction of solar power plants are becoming a more competitive option [78]. Brazil is a country with large inhabitable areas with high solar irradiation, which could be exploited by building solar power plants with photovoltaic systems or concentrated solar power towers.

Whereas production of solar electrical power has still a very small significance in Brazil, thermal energy by solar TCs has expanded and heavily contributed for the reduction of energy consumption in water heating. Currently, there are about 6 million m^2 of TCs installed for water heating, generating 4,000 MW of thermal energy, generating twice the power capacity of Angra I and II together [79]. A rapid growth of these TCs are expected by a combination of: policy incentives using state and local laws; Governmental programs such as "Minha Casa, Minha Vida" ("My House, My Life" in Portuguese) with the subsidize for TCs installation; and the low costs of manufacturing these TCs with recycled or reused materials [80].

The prospect for future use of solar energy goes beyond the production of electricity or heat. As examples, it can cited hybrid lighting systems carrying sunlight directly to the buildings inside through optical fibers [81], and the so-called reverse combustion using big solar concentrators to transform carbon dioxide into liquid fuels [82].

3. Fossil fuel sources of energy

For many years to come, fossil fuels will continue to be the predominant source of energy in the world, as reported by the IEA in the Energy Technology Perspectives report. Alternatively, this scenario opens up an opportunity for research of materials able to contribute by increasing efficiency of the present technologies and lowering costs for sequestering CO_2 in the atmosphere.

3.1. Oil and natural gas

Based on IEA data, Brazil will grow into the third most important oil supplier by 2035 [83]. Unconventional resources, including tight sands, coalbed methane, gas shales, oil found in low-permeability formations, heavy oil deposits, tar sands, and oil shales are particularly attractive resources to producers of natural gas and petroleum due to their long-life reserves. Much of unconventional oil production is currently found in North America, South America and Indonesia, but significant amounts can be found in other basins around the world [84].

The pre-salt may allow Brazil to become a leading global producer of oil and natural gas. Petrobras alone has plans to produce 3.95 million barrels of oil per day in 2020, with 1,08 million barrels coming from the pre-salt reservoirs. Between 2000 and 2010, proven reserves of oil and natural gas in Brazil advanced 68.5%, according to the National Agency of Petroleum, Natural Gas and Biofuels (ANP), which was an increase from 9.854 billion barrels of oil equivalent (boe) to 16.609 boe [83]. The discovery of the first three pre-salt fields in the country, Tupi, Iara and Whale Park, the proven reserves rose from 14 billion barrels to 33 billion barrels. Additional reserves are expected to be of 50 to 100 billion barrels [21].

In the last decade, Brazil has also won the overall lead in discoveries of new reserves, according to a survey of the IHS Cera Consultancy. Considering the volume and number of wells with more than 1 billion barrels, 11 of the 35 largest global discoveries have occurred in the country, surpassing even the Middle East nations, traditionally recognized for hosting the largest deposits

Table 7
UTE—Coal thermoelectric operating in Brazil, 2012 [90].

Name	(kW)	Holder	City, State	Grid[a]
Presidente Medici A e B	446,000	100% Cia de Energia Eletrica	Candiota, RS	PS
Jorge Lacerda IV	363,000	100% Tractebel S/A	Capivari de Baixo, SC	IP
Candiota III	350,000	100% Cia de Energia Eletrica	Candiota, RS	IP
Jorge Lacerda III	262,000	100% Tractebel S/A	Capivari de Baixo, SC	IP
Jorge Lacerda I e II	232,000	100% Tractebel S/A	Capivari de Baixo, SC	IP
Alunorte	103,854	100% Alumina do Norte do Brasil S/A	Bacarena, PA	AP
Alumar	75,200	100% Aluminio do Maranhão	Sao Luis, MA	AP
Charqueadas	72,000	100% Tractebel S/A	Charqueadas, RS	IP
São Jeronimo	20,000	100% Cia de Energia Eletrica	Sao Jeronimo, RS	PS
Figueira	20,000	100% Copel S/A	Figueira, PR	PS
Total: 10 units			**Power: 1,944,054 kW**	

[a] PS: Public Service, IP: Independent Production, AP: Auto-Production.

in the world. According to PFC Energy Consultancy, Brazil is ready to strengthen its position as a leader in deepwater technology and a major oil exporter [83]. While the new findings extend the provision of oil and gas, they also pose technological challenges in various areas, including materials engineering. The discovery of the Pre-Salt reserves brought a number of challenges for Petrobras, including the development of directed technologies and materials that will withstand high pressures, high temperatures and high stresses conditions to drill deeper wells. However, NPC reports that commercialization of new technologies take an average of 16 years to progress from concept to widespread use in the industry [85].

Brazil is expected to increase its refining capacity to process oil extracted from the pre-salt province and go from importing to exporting oil and its derivates. The oil state-owned company decided to expand its refining capacity by 1.2 million barrels per day, and this increase can make Brazil self-sufficient in oil products up to 2013 [86]. Presently, there are imports of LPG, jet fuel, diesel, and naphtha in addition to around 300,000 bpd of light oil, which are used for manufacturing lubricants, and for blending with heavy oil for processing. Since 2008, the oil state-owned company alone has invested US$ 800 million per year in scientific research and various forms of partnerships with universities and suppliers [87]. Main challenge is to solve exploration in ultra-deep waters and refining of heavy and ultra-heavy oils with lower environmental impact [88]. There is together a need to develop technology for reducing costs and optimizing the production in mature fields and pre-salt reservoirs; in the development of technologies for the second generation biofuels; for the effluent zero process and emissions; and carbon capture and storage. Requirements for oil exploration and more specifically those of the pre-salt layer are divided into challenges of corrosive processes and synergistic process, where the source and defect must be carefully analyzed and researched to be developed into materials that can meet the needs of industry. In this context it is possible to continue the discussion by citing the source of the problems and the research opportunities for the generation of knowledge valuable to the exploration and production of hydrocarbons, as well as the development of new materials coming to meet their needs [89].

With the commitment to maximize energy efficiency, additional investments of US$ 1 billion in projects and US$ 200 million in research and development were established in 2010 [90]. For example, PROCLIMA (Climate Change Technology Program) and PROCO2 (Technology Program Management of CO_2) will be the responsible for CO_2 capture, transport and geological storage, emission mitigation in processes and products. Since 2005, those issues were incorporated into the country's oil and gas management and such programs to develop and implement technological solutions were mainly started to prevent and reduce the CO_2 emissions in the atmosphere.

3.2. Coal thermopower

As mentioned, IEA experts estimate that demand for coal will increase over the next two decades more than any other energy source, except for wind and solar, from current levels of about 6.7 billion tons per year to nearly 10 billion tons in 2030 [32]. China and India are the main factors behind the increased demand for coal, and the two countries already account for more than half of the global demand, with the establishment of new coal plants ever more necessary. In Japan, after the disaster in Fukushima, use of fossil fuels underwent a 20% increase in imports and exports [91], followed by Germany which will also rely on them in the short-term [92]. The halving of the fossil-fuels energy worldwide is promoting more advanced studies in technologies for Carbon Capture and Storage (CCS). CCS technologies are typically divided into three main methods: post-combustion, pre-combustion, and oxy-combustion [35]. Ongoing large-scale demonstration and field testing projects were recently listed by Abbasi and Abbasi [37].

In Brazil, the current production of coal is about 6.0 Mt, used almost entirely for electricity generation (Table 7). In steelmaking, the coal is imported for the production of coke with a total of 15 Mt [5].

A major concern related to coal mining is the environmental degradation that is directly linked to the use of raw material for power generation [93]. An alternative for this problem could be its production by in-situ gasification which is generated by the same chemical reactions that occur in conventional gasification adjusting the gasifying agent and ratio to carbonaceous feedstock [94]. As gasification process occurs in the underground with no mining of the coal deposit, it has some important advantages as reduction of ecological damage in air pollution and soil degradation. Costs related to the gasifier and their aides are dismissed, since the process reactor is the coal seam itself, the residues are generated in the coal seam itself reducing costs of waste disposal and treatment. But the great advantage of this technique is related to its potential in combining carbon capture and sequestration. As the geological repository is able to trap these gases, underground gasification is one of the most environmentally friendly solutions in order to keep fossil-fuels exploration. Another alternative being explored in countries such as China and South Africa are coal liquefaction to produce diesel and jet fuels [95].

4. Nuclear energy

Of all the non-fossil fuel technologies, nuclear energy is in the final stages for large-scale deployment. Even though operation

Table 8
UTN—Nuclear power plants operating in Brazil, 2012 [41].

Name	(kW)	Holder	City, State	Grid[a]
Angra I	657,000	100% Eletrobras Termonuclear S/A	Angra dos Reis, RJ	PS
Angra II	1,350,000	100% Eletrobras Termonuclear S/A	Angra dos Reis, RJ	PS
Total: 2 units			**Power: 2,007,000 kW**	

[a] PS: Public Service.

has been technically demonstrated, there are still serious questions about nuclear waste material produced. And natural uranium resources may not be large enough to support larger demand, which would arise if nuclear fission becomes important in the world energy supply.

As already mentioned, there are two operating thermonuclear power plants (UTN) placed in the populated southwest of Rio de Janeiro (Table 8), Angra I and Angra II, with a total capacity of 2,007 kW [41]. From the generated power capacity, nuclear energy contributes with a share of 1.6% in the Brazilian matrix as shown in Fig. 1. Angra I (in operation since 1984) and Angra II (since 2000) are regulated by the CNEN (National Commission of Nuclear Energy). The CNEN is a federal autarchy, created in 1956 and linked to the Ministry of Science and Technology, responsible for the mining of radioactive elements, production and commerce of nuclear materials. The CNEN together with the IBAMA (Brazilian Institute of the Environment and Natural Renewable Resources) have given the final license for the construction of a third thermonuclear power plant, Angra III, with a capacity of 1,350 kW to be fully running by 2015 [42]. This nuclear facility represents 5.0% of the total power capacity under construction and it is an initiative to promote diversification of the energy matrix [18].

In addition, Brazilian uranium reserves have been proven to be vast, with an estimated 279,000 t of U and 5.0% of world known recoverable resources [43]. Even though uranium exploration in Brazil started as early as 1953 with the discovery of the first deposits in Minas Gerais and Bahia states, only in 2003 it was started the construction of a commercial-scale enrichment facility at Resende, in Rio de Janeiro state. A recent work comparing the Brazilian enrichment costs with the price of the enriched uranium in the international market concludes that Brazil is willing either to pay a risk to assure its nuclear fuel supply or for the option of increasing capacity in the future to lower average costs, or both [44].

Even with these hypotheses based on the Governmental strategy and Brazil estimated potential, increase of nuclear power participation into the energy matrix is not likely to occur shortly. Such decision would have to pass through public acceptance and also other regulatory aspects with discussions about a crucial and important fact that is the unsolved management and logistic of radioactive waste.

5. Hydrogen energy

Main roles of hydrogen in the future energy economy are as follows: storing energy for intermittent sources (i) and substituting oil with the use of fuel cells (ii). Wind turbine and solar cells capture energy contained in wind and sun, respectively, which can be immediately consumed or stored. Water electrolysis is used to produce hydrogen and then store it when wind blows or sun shines more. Current initiatives are mainly concentrated on option (ii). As an example, residues from ethanol production are being used to produce hydrogen from glycerol [96]. Additionally, Petrobras has patented a green diesel as H-BIO which is a novel fuel resulting from a reaction of hydrogen and bio-oil as follows [97]:

$$100\ \text{L bio-oil} + 35\ \text{Nm}^3\ H_2 = 96\ \text{L of H-BIO} + 2.2\ \text{Nm}^3\ \text{of propane}$$

Recently, the Center of Management and Strategic Studies under the supervision of the Brazilian Ministry of Science and Technology has published a document titled: Energetic Hydrogen in Brazil: funding for competitive politics 2010–2025 ("Hidrogenio energetico no Brasil: subsidios para políticas de competitividade 2010–2025" in Portuguese), giving numbers of a hydrogen scenario in the country related to its research, technologies and funding [45]. The document reports Brazil as a leader in Latin America but yet with an investment in hydrogen technologies of only 3 to 5% of Japan, European Union, or the United States. National hydrogen production is about 920,000 t (10.2 billion cubic meters) per year with only 1% used as a direct fuel and the other 99% for refining, petrochemical, fertilizers and methanol.

6. Final considerations

Population growth associated with increased life expectancy, development of economic activity and income growth of the population generates a need for increased energy production. The replacement of fossil fuels is important as a way of reducing CO_2 emissions, contributing to reducing the greenhouse effect and its devastating consequences.

6.1. Hydropower

Apparently, hydropower will continue to be the major source of energy in the country. Technology is mature and challenges in materials research are few and mainly related to pitting resistance of the blades, which have been over-passed with high resistance alloys, and coating treatment. Thus, problems related to this source of energy are of social and environmental concerns.

6.2. Biomass

According to IEA, in approximately 20 years nearly 30% of total energy consumption will be from renewable sources. Currently, renewables other than hydroelectric power accounts for 12.0% of the global matrix with biomass being 9.73%. The future of biomass as an energy source is very promising, especially in underdeveloped countries, where waste generation for this purpose is very large. Allied to the development of new techniques and new materials, growth and development of power generation from biomass has only increased year by year.

6.3. Eolian

According to PROINFRA, wind energy is the main alternative renewable source in Brazil, with a potential to generate 143.5 GW, or 272.2 TWh per year, it is believed that the number of wind power plants will increase from 73 to 141, despite that Brazil has

no significant contribution to technology research in this area because the main components used in wind energy production are imported due to the difficulty of obtaining materials with the required properties, in addition to problems caused by corrosion. It is hoped the increased use of natural materials in blades is made of reinforced composites.

6.4. Solar

It is estimated that until 2030 the production of solar energy will reach 29% of renewable energy (1,619 TWh). Brazil has large areas favorable to the generation of energy due to high solar irradiation, this energy source has fast growth, but the solar power generation is very low due to problems such as lack of favorable public policies, high prices and isolated areas where the transmission of power is complicated. The largest use of energy is done autonomously to generate only small amounts for personal use, but the outlook for the future use of solar energy goes beyond the production of electricity or heat.

6.5. Oil and natural gas

The indicators show that Brazil is becoming a leading global producer of oil and natural gas primarily due to discoveries of new reserves in the pre-salt area. These findings, in addition to placing Brazil as a leader in deepwater technology and as the third most important country in terms of oil supply by 2035, present challenges for many different research areas, including materials engineering. Aiming to solve these challenges, as well as to minimize the environmental impacts caused by the pre-salt exploitation, oil companies are investing significant amounts in research and development projects, offering, so, opportunities to researchers from diverse fields of technology.

6.6. Coal

It appears that even with the increase of renewable energy in the global matrix, there was still growth of fossil fuels. Because of this, there are currently many research efforts for the development and implementation of underground gasification and carbon capture sequestration, given the huge demand for obtaining energy in a cleaner way. However, much remains to be done regarding the development of cheaper new materials available for the coal industry, current bottlenecks for underground gasification and other environmentally friendly alternatives for energy production from coal.

6.7. Nuclear

Brazil has two nuclear power plants currently in operation and a third is under construction. Nuclear power in the Brazilian grid contributes only with a small share, thus the deployment of a new plant aims to diversify energy sources in the country. Moreover, Brazil has reserves of uranium with a representative size. However, nuclear power production is still questioned because of radioactive wastes, which results from energy generation.

6.8. Hydrogen

Strategies such the ones generating hydrogen from natural gas, petroleum or coal with CO_2 sequestration may be embraced by Petrobras with the starting of pre-salt exploration. Apart from that, national efforts related to hydrogen technologies are expected to continue with research in the three main areas (proton exchange membrane fuel cells, solid oxide fuel cells, and catalysts for ethanol reforming) and funded by the government (as about 70% of the research being developed in the country) with few participation from the private sector.

To conclude, Brazil has already important energy programs running with strong legal frameworks supported by its government, but still there is greatly unexplored potential to create a solid cycle of energy generation and distribution with economy and at the same time sustainable advantages.

Acknowledgments

The authors thank the Materials Science Post-Graduation Program (PGMAT) for offering the course “Materials and Sustainability”. We are also grateful to the Brazilian National Research Council (CNPq) and the Coordination for the Improvement of the Higher Education Personnel (CAPES).

References

[1] ENERDATA. Global Energy Intelligence. Yearbook. Available online at ⟨www.enerdata.net⟩; 2011. p. 12.
[2] You J. China's energy consumption and sustainable development: comparative evidence from GDP and genuine savings. Renewable and Sustainable Energy Reviews 2011;15:2984–9.
[3] IBGE. Brazilian Institute of Geography and Statistics. Available online at ⟨http://www.ibge.gov.br/english⟩.
[4] PAC2. Programa de Aceleracao de Crescimento/Growth Acceleration Plan. Energy 2011. Available at ⟨http://www.brasil.gov.br/pac/relatorios/2011-nacionais/eixo-energia⟩ [In Portuguese].
[5] EPE-MME. Energy Research Company of Ministry of Mines and Energy. 2030 PNE—Plano Nacional de Energia/National Energy Plan. Available at ⟨http://epe.gov.br/PNE/20080512_3.pdf⟩ [In Portuguese].
[6] Progisys S. Growth of oil and gas industries in Brazil drives demand for a higher quality of candidates. Brazil Oil and gas 2011;18:20–1.
[7] de Souza HM, Leonelli PA, Alexandre C, Pires P. Reflexoes sobre os principais programas em eficiencia energetica existentes no Brasil. Revista Brasileira de Energia 2009;15:7–26.
[8] PROCEL. Programa Nacional de Conservação de Energia Elétrica/National Program of Electrical Energy Conservation. Available at ⟨www.eletrobras.com/procel⟩ [In Portuguese].
[9] CONPET. Programa Nacional da Racionalização do Uso dos Derivados do Petroleo e do Gás Natural. National Program of Rationalized Use of Oil and Natural Gas Derivates. Available at ⟨www.conpet.gov.br⟩ [In Portuguese].
[10] PBE. Programa Brasileiro de Etiquetagem/Brazilian Program on Labeling. Available at ⟨http://www.inmetrogovbr/qualidade/eficienciaasp⟩ [In Portuguese].
[11] PNMC. Programa Nacional de Mudanças Climáticas/National Program of Climate Change. Available at ⟨http://www.mma.gov.br/estruturas/169/_arquivos/_29092008073244.pdf⟩ [In Portuguese].
[12] ANEEL. Agência Nacional de Energia Elétrica/National Agency of Electrical Energy. Available at ⟨http://wwwaneelgovbr⟩ [In Portuguese].
[13] ANP. Agência Nacional de Petroleo, Gas Natural e Biocombustiveis/National Agency of Oil, Gas and Biofuels. Available at ⟨http://www.anpgovbr/⟩ [In Portuguese].
[14] INMETRO. Instituto Nacional de Metrologia, Normalização e Qualidade Industrial/ National Institute of Metrology, Normalization and Industrial Quality Control. Available at ⟨http://www.inmetrogovbr/⟩ [In Portuguese].
[15] CNPE. Concelho Nacional de Politica Energetica/National Council of Energetic Politics. Available at ⟨http://www.mmegovbr/mme/menu/conselhos_comite/cnpehtml1997⟩ [In Portuguese].
[16] PNEE. Plano Nacional de Eficiencia Energetica/National Plan of Energetic Efficiency. Available at ⟨http://www.mme.gov.br/mme/galerias/arquivos/noticias/2010/PNEf_-_Premissas_e_Dir._Basicas.pdf⟩; 2010 [In Portuguese].
[17] EPE. Empresa de Pesquisa Energetica/Energy Research Company. Available at ⟨http://www.epe.gov.br⟩ [In Portuguese].
[18] ANEEL. Brazilian Energy Capacity. Available at ⟨http://www.aneelgovbr/aplicacoes/capacidadebrasil/capacidadebrasilasp⟩ [In Portuguese].
[19] ANEEL. Electrical Energy Matrix: in Operation. Available at ⟨http://www.aneelgovbr/aplicacoes/capacidadebrasil/OperacaoCapacidadeBrasilasp⟩ [In Portuguese].
[20] PETROBRAS. Operations in the Pre-Salt. Discoveries. Available online at ⟨http://www.petrobras.com.br/en⟩; 2005.
[21] PETROBRAS. Pre-salt/Pré-sal. Available at ⟨http://wwwpetrobrascombr/minisite/presal2009⟩ [In Portuguese].
[22] Brown LR, Plan B. 4.0: Mobilizing to save civilization. New York: W. W. Norton & Company; 2009.
[23] Henriques MF, Dantas F, Schaeffer R. Potential for reduction of CO_2 emissions and a low-carbon scenario for the Brazilian industrial sector. Energy Policy 2010;38:1946–61.
[24] Lampreia J, de Araujo MSM, de Campos CP, Freitas MAV, Rosa LP, Solari R, et al. Analyses and perspectives for Brazilian low carbon technological

development in the energy sector. Renewable and Sustainable Energy Reviews 2011;15:3432–44.
[25] ANEEL. Generation Capacity in Brazil: UHE (Hydroelectric Usines) type in operation. Available at 〈http://www.aneelgovbr/aplicacoes/capacidadebrasil/GeracaoTipoFaseasp?tipo=1&fase=3〉 [In Portuguese].
[26] ANEEL. Generation Capacity in Brazil: CGH (Hydroeletric Generation Central) type in operation. Available at 〈http://www.aneelgovbr/aplicacoes/capacidadebrasil/GeracaoTipoFaseasp?tipo=10&fase=3〉 [In Portuguese].
[27] ANEEL. Generation Capacity in Brazil: PCH (Hydroeletric Small Central) type in operation. Available at 〈http://www.aneelgovbr/aplicacoes/capacidadebrasil/GeracaoTipoFaseasp?tipo=5&fase=3〉 [In Portuguese].
[28] Itaipu. Binacional, Brazil-Paraguay. Available at 〈http://wwwitaipugovbr/en/energy/energyMarch〉, 2012 [In Portuguese].
[29] ANEEL. CGU (Wave Generation Central) type in issue. Available at 〈http://www.aneelgovbr/aplicacoes/capacidadebrasil/GeracaoTipoFaseasp?tipo=11&fase=1〉 [In Portuguese].
[30] IEA. International Energy Agency. Oil Market Report 2011. Available online at 〈http://www.oilmarketreport.com/〉.
[31] BP. British Petroleum. Statistical Review of World Energy. Review by energy type. Available online at 〈www.bp.com/statisticalreview〉; 2011.
[32] IEA. International Energy Agency. Energy Technologies Perspectives. Available online at 〈http://www.iea.org/techno/etp/etp10/English.pdf〉; 2010.
[33] ABCM. Brazilian Mineral Coal Association. Dados Estatísticos/Statistics. Brazil. Available at 〈http://www.carvaomineral.com.br〉 [In Portuguese].
[34] Benson SM, Orr FM. Carbon dioxide capture and storage. Harnessing materials for energy. MRS Bulletin 2008;33:303–5.
[35] Florin N, Fennell P. Review of advanced carbon capture technologies. Work stream 2, Report 5A of the AVOID programme. Available online at 〈www.avoid.uk.net〉; 2010. p. 1–28.
[36] Hester RE, Harisson RM. Carbon capture: sequestration and storage issues. Environmental Science and Technology 2010;29:P001–4.
[37] Abbasi T, Abbasi Sa. Decarbonization of fossil fuels as a strategy to control global warming. Renewable and Sustainable Energy Reviews 2011;15:1828–34.
[38] CEPEL. Center of Electrical Energy Research. Wind Map of Brazil/Atlas do Potencial Eólico Brasileiro. Available at 〈http://www.cresesbcepelbr/publicacoes/download/atlas_eolico/Atlas%20do%20Potencial%20Eolico%20Brasileiropdf〉 [In Portuguese].
[39] Salamoni IT. Um programa residencial de telhados solares para o Brasil: diretrizes de políticas públicas para a inserção da geração fotovoltaica conectada à rede elétrica. Doctorate. Florianopolis: Universidade Federal de Santa Catarina; 2009.
[40] ANEEL. Photovoltaic usines in operation. Available at 〈http://www.aneelgovbr/aplicacoes/capacidadebrasil/GeracaoTipoFaseasp?tipo=12&fase=3〉 [In Portuguese].
[41] ANEEL. Thermonuclear power plans: in operation and under constructions. Available at 〈http://www.aneelgovbr/aplicacoes/capacidadebrasil/Nuclearasp〉 [In Portuguese].
[42] CNEN. Comissão Nacional em Energia Nuclear/National Commission on Nuclear Energy—NN 6.02: Licenciamento de Instalações Radiativas/License of Radioactive Instalations; 2008.
[43] Kidd S. Uranium supply for the nuclear future. Energy and Environment 2011;22:61–6.
[44] Cabrera-Palmer B, Rothwell G. Why is Brazil enriching uranium? Energy Policy 2008;36:2570–7.
[45] Assunção FCR. Hidrogênio energético no Brasil: subsídios para políticas de competitividade, 2010–2025. Tecnologias críticas e sensíveis em setores prioritários. Brasilia: Centro de Gestão e Estudos Estratégicos/CGEE; 2010.
[46] Antolini E, Perez J. The use of rare earth-based materials in low-temperature fuel cells. International Journal of Hydrogen Energy 2011;36:15752–65.
[47] Batista MS, Santos RKS, Assaf EM, Assaf JM, Ticianelli EA. High efficiency steam reforming of ethanol by cobalt-based catalysts. Journal of Power Sources 2004;134:27–32.
[48] Fonseca FC, Uhlenbruck S, Nedéléc R, Buchkremer HP. Properties of bias-assisted sputtered gadolinia-doped ceria interlayers for solid oxide fuel cells. Journal of Power Sources 2010;195:1599–604.
[49] Hotza D, Diniz da Costa JC. Fuel cells development and hydrogen production from renewable resources in Brazil. International Journal of Hydrogen Energy 2008;33:4915–35.
[50] Liberatori JWC, Ribeiro RU, Zanchet D, Noronha FB, Bueno JMC. Steam reforming of ethanol on supported nickel catalysts. Applied Catalysis A: General 2007;327:197–204.
[51] Moreira MV, da Silva GE. A practical model for evaluating the performance of proton exchange membrane fuel cells. Renewable Energy 2009;34:1734–41.
[52] Muccillo R, Muccillo ENS, Fonseca FC, França YV, Porfirio TC, de Florio DZ, et al. Development and testing of anode-supported solid oxide fuel cells with slurry-coated electrolyte and cathode. Journal of Power Sources 2006;156:455–60.
[53] Padilha JC, Basso J, da Trindade LG, Martini EMA, de Souza MO, de Souza RF. Ionic liquids in proton exchange membrane fuel cells: efficient systems for energy generation. Journal of Power Sources 2010;195:6483–5.
[54] Holdren JP. Materials genome initiative of global competitiveness. In: National Science and Technology Council OSTP, editor. Washington; 2011.
[55] Truscott GF. A literature survey on abrasive wear in hydraulic machinery. Wear 1972;20:29–50.
[56] Cline R. Mechanical overhaul procedures for hydroelectric units. Facilities instructions, standards, and techniques. Denver, Colorado: United States Department of the Interior Bureau of Reclamation; 1994.
[57] Duncan WJ. Turbine repair. Facilities instructions, standards and techniques. Denver, Colorado: United States Department of the Interior Bureau of Reclamation; 1989.
[58] Krishnamachar P, Rangnekar S. Correlation of hydropower potential of silt load of rivers—means to access damage by silt due to not harnessing hydropower. In: Publications H, editor. HydroVision. Kansas City, Mo, USA; 2008.
[59] Nigam PS. Handbook of hydro electric engineering. India: Nem Chand & Bros; 2008.
[60] Pereira MG, Camacho CF, Freitas MAV, da Silva NF. The renewable energy market in Brazil: current status and potential. Renewable and Sustainable Energy Reviews 2012;16:3786–802.
[61] Erdogdu E. An analysis of Turkish hydropower policy. Renewable and Sustainable Energy Reviews 2011;15:689–96.
[62] Kuwahata R, Monroy CR. Market stimulation of renewable-based power generation in Australia. Renewable and Sustainable Energy Reviews 2011;15:534–43.
[63] Falcao O. Wave energy utilization: a review of the technologies. Renewable and Sustainable Energy Reviews 2010;14:899–918.
[64] OECD/IEA. Bioenergy Project Development and Biomass Supply Paris: IEA report; 2007.
[65] Kiplagat JK, Wang RZ, Li TX. Renewable energy in Kenya: Resource potential and status of exploitation. Renewable and Sustainable Energy Reviews 2011;15:2960–73.
[66] Coelho ST, Guardabassi P, Grisoli R. The Brazilian experience with biofuels/A experiência brasileira com biocombustíveis. Magazine of the Swiss-Brazilian Chamber of Commerce. Available at 〈http://www.swisscam.com.br/assets/files/magazine/magazine_66.pdf2011〉. p. 3 [In Portuguese].
[67] Farrell AE, Gopal AR. Bioenergy research needs for heat, electricity, and liquid fuels. MRS Bulletin 2008;33:373–80.
[68] Kirkels AF, Verbong GPJ. Biomass gasification: still promising? A 30-year global overview Renewable and Sustainable Energy Reviews 2011;15: 471–81.
[69] Lora ES, Andrade RV. Biomass as energy source in Brazil. Renewable and Sustainable Energy Reviews 2009;13:777–88.
[70] Peláez-Samaniego MR, Garcia-Perez M, Cortez LB, Rosillo-Calle F, Mesa J. Improvements of Brazilian carbonization industry as part of the creation of a global biomass economy. Renewable and Sustainable Energy Reviews 2008;12:1063–86.
[71] de Castro C, Mediavilla M, Miguel LJ, Frechoso F. Global wind power potential: physical and technological limits. Energy Policy 2011;39:6677–82.
[72] WWEA. World Wind Energy Association. Interactive World Map. Available online at 〈http://www.wwindea.org/home/images/stories/Information%20Center/Final/deploy-to-web/main.swf〉; 2010.
[73] WWEA. World Wind Energy Association. Report. Available online at 〈http://www.wwindea.org/home/images/stories/pdfs/worldwindenergyreport2010_s.pdf2011〉.
[74] Michalak P, Zimny J. Wind energy development in the world, Europe and Poland from 1995 to 2009; current status and future perspectives. Renewable and Sustainable Energy Reviews 2011;15:2330–41.
[75] Hayman B, Wdel-Heinen J, Brondsted P. Materials challenges in present and future wind energy. MRS Bulletin 2008;33:343–53.
[76] Siemens. Worldwide power generation. Pictures of the Future: Available online at 〈http://www.siemens.com/innovation/pool/en/publikationen/pof-special-edition-e-double.pdf〉; 2009. p. 59.
[77] REN21. Renewables 2010 Global Status Report. Available online at 〈http://www.ren21.net/Portals/97/documents/GSR/REN21_GSR_2010_full_revised%20Sept.pdf〉.
[78] Rüther R, Zilles R. Making the case for grid-connected photovoltaics in Brazil. Energy Policy 2011;39:1027–30.
[79] ABRAVA. Brazilian association of cooling, air conditioning, ventilation, and heating. Já são 6 milhões de metros quadrados de aquecimento solar/There is already 6 million cubic meters of solar heating. Conexao AEC. Available at 〈http://www.aecweb.com.br/aec-news/materia/4229〉; 2010 [In Portuguese].
[80] Alano JA Manual for the construction and instalation of heat solar collectors with recyclabes. Premio Super Ecologia. Tubarao, SC, Brazil. Available at 〈http://josealcinoalano.vilabol.uol.com.br/manual.htm〉; 2004 [In Portuguese].
[81] Mayhoub M, Carter D. Um estudo de viabilidade dos sistemas de luminação híbridos. Eletricidade Moderna 2010:58–72.
[82] Service RF. Sunlight in your tank. Science: AAS 2009:1472–5.
[83] Medeiros V. Profundo Futuro. Petrobras Magazine 2011;60:42–7.
[84] Holditch SA, Chianelli RR. Factors that will influence oil and gas supply and demand in the 21st century. MRS Bulletin 2008;33:317–23.
[85] National Petroleum Council. Facing the hard truths about energy—acomprehensive view to 2030 of global oil and natural gas. Washington, DC: NPC; 2008.
[86] Progisys SA. New Petrobras. Brazil Oil and gas 2011;18:5–9.
[87] Tautz C. Cérebros made in Brazil. Petrobras Magazine 2011;60:37–41.
[88] COPPE/UFRJ. Corrida para o mar—Os desafios tecnológicos e ambientais do pré-sal/Running to the Sea—Technological and environmental challenges of pre-salt. Available at 〈http://www.coppeufrjbr/coppe/publicacoeshtml2010〉 [In Portuguese].
[89] Henriques CCD. Desafios na Seleção de Materiais na Indústria do Petróleo/Challenges of the Materials Selection in the Oil Industry. IX Seminário Brasileiro do Aço Inoxidável. Available at 〈http://www.nucleoinox.org.br/biblioteca-seminario-brasileiro.php〉; 2008 [In Portuguese].

[90] Gianordoli G. Gestão de Emissões. Petrobras Magazine 2011;61:42–3.
[91] Cyranoski D. Japan's new leader faces energy gap. Nature 2011:13–4.
[92] Van Noorden R. The knock-on effects of Germany's nuclear phase-out. Naturenews 2011.
[93] Haag WO, Kuo JC, Wender I. Gasification for the synthesis of fuels and chemicals. Energy 1987:689–728.
[94] Mondal P, Dang GS, Garg MO. Syngas production through gasification and cleanup for downstream applications—recent developments. Fuel Processing Technology 2011;92:1395–410.
[95] Patel P, Fiato R. China and South Africa pursue coal liquefaction. MRS Bulletin 2012;37:204–5.
[96] de Souza ACC, Silveira JL. Hydrogen production utilizing glycerol from renewable feedstock: the case of Brazil. Renewable and Sustainable Energy Reviews 2011;15:1835–50.
[97] Biodiesel. H-BIO: o novo diesel da Petrobras. Available at 〈http://www.biodieselbr.com/destaques/2006/h-bio-novo-diesel-petrobras.htm〉; 2006 [In Portuguese].